CONCLUSIONS

An analysis that derives the hydraulic geometry for river estuaries is presented. It combines hydraulic geometry relationships developed for fluvial channels with those developed more recently for tidal channels. Results obtained from this analysis are compared to channel features reconstructed from an 1860 U.S. Coastal Survey of the Napa River Estuary prior to human impacts. The comparison suggests the existence of a transition zone where fluvial and tidal processes interact to shape the channel cross-section. Within this transition zone, the stable channel cross-section can vary within the envelope bounded by the fluvial and tidal hydraulic geometry relationships.

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Morphodynamics of a former polder (Sieperdaschor) after breaching of the summer dike in the Scheldt estuary, SW Netherlands

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ABSTRACT

After breaching of the summer dike in 1990, a former polder of 98 ha is now changing into a tidal marsh in the Scheldt estuary. This development is followed closely, for it serves valuable information on wetland restoration processes. The results up to now show that tidal energy is sufficient for creek formation. The new creek pattern still resembles the artificial ditch pattern, present at time of inundation. After 6 years most creeks are still widening and this will continue for at least another decade. Sediment budget calculations show that the marsh is importing sediments form the estuary. However, about 25% of the net accretion is redistribution of sediments from the eroding creeks towards the marsh surface.

INTRODUCTION

Due to the accidental breaching of the summer dike in 1990 and the non-interference afterwards the "natural" restoration of a former polder into a tidal marsh can be followed in the Scheldt estuary in the southwest part of The Netherlands on the border with Belgium (Figure 1). The folder polder area of 98 ha, called the Sieperdaschor, has a mean height of 2.4 - 2.8 m above N.A.P. (Dutch ordnance level ≈ mean sea level). It has a leg-shaped, narrow but elongated form: between 200 m and 500 m wide and 3500 m long. Before the construction of a pipeline dam in 1966, the area was part of the Land van Saeftinge, a Ramsar area of over 3000 ha of tidal flats and marshes (Figure 2[a]). The restoration of the Sieperdaschor into a tidal marsh is one of the topics in the Integrated Water Management of the Scheldt estuary.

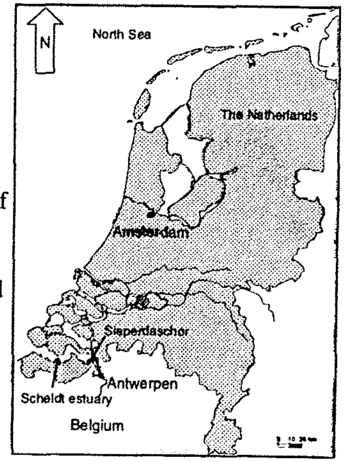

Figure 1. Location of Sieperdaschor in the brackish part of the Scheldt Estuary

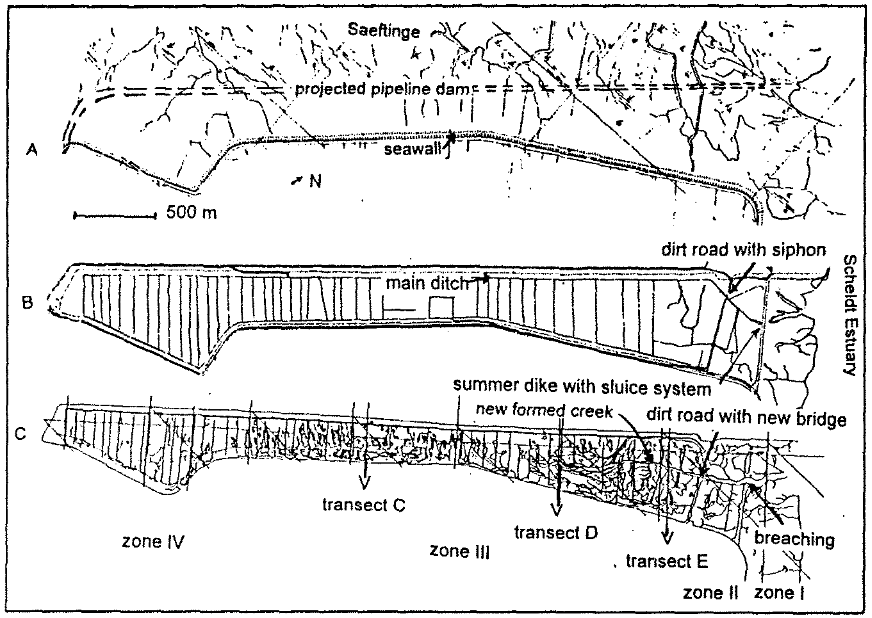

Figure 2. The Sieperdaschor in different situations: (a) as a part of a large marsh (before 1966), (b) as a polder (1966-1990) and (c) the present situation: changing into a tidal marsh

Due to further deepening of the fairway to the port of Antwerpen in Belgium in 1997, a further loss of shallow water, intertidal flats and tidal marshes is expected. One of the ideas to restore these valueable habitats in the most pronounced estuary in The Netherlands is "depoldering" by opening former reclaimed land to the sea (Pieters et.al., 1992). Apart from the restoration of wetlands, the former polder can be useful as a sink for silts and it reduces the maximum high waters in the estuary.

MORPHOLOGICAL DEVELOPMENT

Before the experiment of tidal marsh restoration started in 1990, the polder had a drainage system, consisting of a main ditch alongside the pipeline dam, smaller ditches perpendicular to the main ditch and a sluice system at the polder dike (Figure 2^b). The polder was far from a homogeneous stripe of land. The areas with a more dense ditch network correspond with the relative lower and more clayey soils. These were the backmarsh areas before the reclamation. On the other hand, the parts with fewer ditches are higher and sandier and correspond with the former creeks and levees.

After the breaching of the summer dike, the area was flooded frequently at spring tides. At first tidal flow was mainly restricted to the existing drainage network, especially throught the main ditch, being the preferential route for both flood and ebb flow. Along the sea wall at the southern border of the area, water logging occured.

The drainage infrastructure was originally designed for rainfall and occasional tidal floodings and was not sufficient to drain this part of the polder.

A dirt road crossed the area about 500 m westward of the summer dike. This road was the only access to a big cattle farm and therefore had to be maintained. The main ditch crossed the road with a 1 m wide siphon. Being the bottleneck in the drainage of the marsh, this proved to be a weak point. In 1991 a provisional bridge was build. In 1993 a new creek was dug in the center of the area and a new and wider bridge was constructed (Figure 2^c). The old creek was closed up at the dirt road. An another important change was that the cross-section at the new bridge was much bigger than the former one. This proved to be a new impulse to the increase of tidal flow and creek enlargement within the marsh. Six years after inundation the drainage pattern still resembles the former ditch network. But some new creeks have formed and some older ditches have siltated also.

PRESENT HYDROLOGY

The Sieperdaschor can be zonated in 4 different areas with distinct environmental features (Figure 2^c) related to tidal motion, creek morphology and hydroperiods. The first zone is the reference area with an undisturbed tidal marsh, extending from the Scheldt Estuary to the breached summer dike. The second zone is situated between the former summer dike and the dirt road with the bridge. In this area the tidal influence is almost complety restored. In the third zone, from the dirt road up to about 2/3 of the area, tidal action is still increasing and restoration of the marsh is in progress. The flooding and drainage is still limited due to the passage at the bridge. The fourth zone is situated at the end of the area. There tidal action is too weak to form creeks. Apart from continuous inundation during spring tide, this zone shows the fewest changes since the breaching.

Outside the Sieperdaschor the tidal range varies from 4 m during neap tides to nearly 6 m during spring tides. The mean high water reaches from 2.0 m N.A.P. during neap tide to 3.0 m N.A.P. during spring tide. The tidal wave is slightly asymmetric with shorter flood than ebb duration. The mean tidal range just behind the dirt road changed from 0.75 m to 1.75 m in 1993 due to the new bridge passage. Three years later the mean tidal range has increased up to 2.3 m. In the fourth zone of the marsh the tidal range of 0.2 m was not influenced by the new bridge passage and is slowly reduced over the last years to 0.1 m in 1996, mainly due to siltation in the main ditch.

The neap tide - spring tide cycle is of major importance to the hydrology of the area. During spring tide the slope of the tidal curve is much steeper than during neap tide. During neap tide, the ebb flow stops as drainage is completed before the start of the next flood. During spring tide, the ebb continues to drain the marsh untill the next flood occurs. Drainage is incompleted over a tidal period during spring tide, leaving a surplus of water opn the marsh. Therefore the Sieperdaschor shows a two-weekly drainage period, with water accumulating during spring tides untill the tidal amplitude decays. Afterwards this area is drained slowly.

PRESENT MORPHODYNAMICS

From height transects (Figure 3), which have been measured yearly since 1992 it can be shown that the marsh surface changes very little in the western and middle part (transect C), in contrary to the eastern part (transect D and E), where mean accretion rates of about 3-5 cm/year occur. In transect E it is shown that the formation of the main creek is very fast. The eroded sediments are deposited on the leeves alongside.

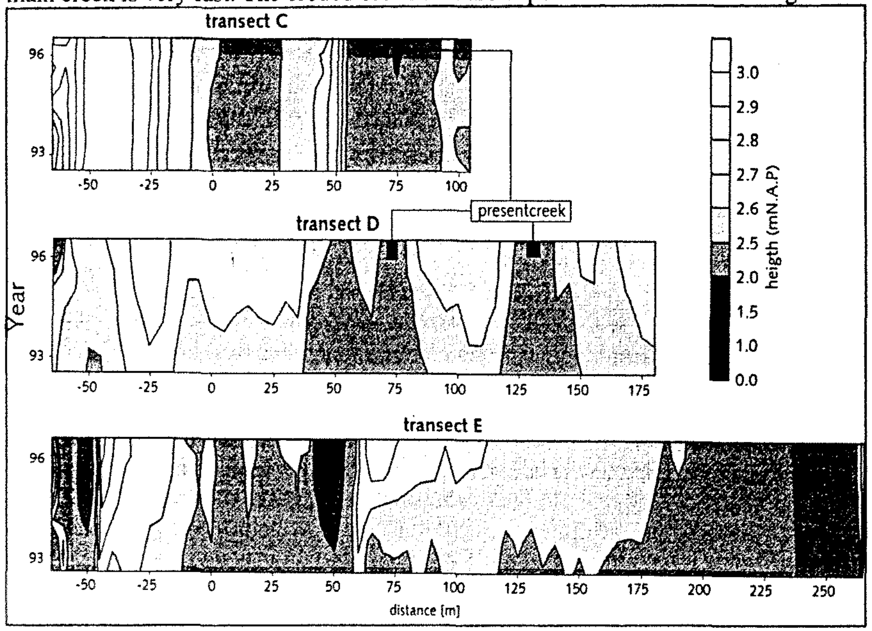

Figure 3. Distance-time plots for the height [m N.A.P.] of the tidal marsh in three cross-sections (see Figure 2^{c}) over the periode 1992 - 1996.

The artificial drainage network from the polder period still plays an important role in the present creek formation. Directly after tidal action was restored, tidal flow started to widen and deepen the main ditches. The ebb flow is very persistent in following the artificial drainage network and short cuts are mostly made by the flood flow. Only later these short cuts are deepened and maintained by the ebb flow. From observations in other "drowned lands" it can be expected that the ideal dendritic pattern as in natural created marshes will never be attained.

Most erosive creeks show a typical U-shape cross-section. After storms the beds are covered with freshly eroded lumps rom the creek banks. This indicates that creek widening especially occurs during these extreme situations. Apart from the widening and deepening of creeks, the creek heads and the so-called steps within the creeks

move landwards. This backward erosion process (Figure 4) is caused mainly by the ebb flow, when drainage is concentrated in the creeks. At the steps where the cross-section are enlarged abruptly, a scour hole is formed due to the high turbulent flow conditions. This scour hole is undermining the cohesive and compacted soils and after slumping the steps are progressing upstream. Further downstream of the scour hole the creek banks become unstable and slide into the creek. The surplus of sediments from the scour hole and the bank slides is partly deposited in the creeks itself, forming the characteristic V-shape cross-section.

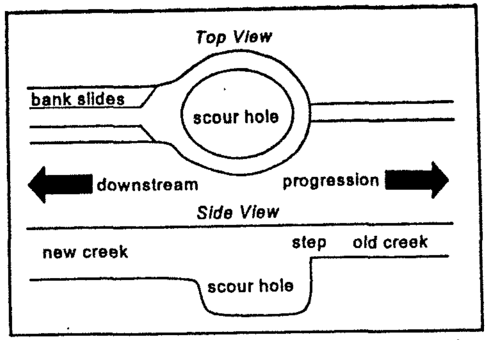

Figure 4. Top and side view of the backward erosion process in the erosive creeks

The sediment budget has been calculated by the product of accretion and area minus the net erosion in the creeks (Sánchez Leal & Storm, 1996). A rough estimate is that about 58,000 m^3 has been deposited on the marsh surface and 14,000 m^3 has been eroded within the creeks. In total 44,000 m^3 of sediments has imported over the last 4 years within 71 ha or 156 m^3 per ha per year. From this it is stated that Sieperdaschor is a sediment importing marsh, with an internal redistribution of about 25% of the net deposition.

EXPECTED DEVELOPMENTS

The creeks are still too small for maximum tidal volumes and therefore it is expected that the creeks upstream of the bridge will further widen up and enlarge, at least for another decade.There is a positive feedback in this enlargement, for larger creeks will facilitate larger tidal volumes and that will in turn lead to further increase of the creek dimensions. Of course, eventually a dynamic equilibrium between tidal volume and creek dimensions will be reached. This will happen as further creek widening does not result anymore in an increase of the tidal volume. The tidal prism of the marsh will decrease due to sedimentation on the marsh surface which amounts to several cm's per year. Accretion of the marsh will continue until the level of extreme high water is reached.

There are two more or less extreme scenarios for future marsh development. One scenario is that formation of creeks, levees and backmarshes will extend up to the landward end of the former polder. The drainage of the polder will increase and places with standing water will diminish. The second scenario is that active creek formation will be restricted to the proximal (first) part of the marsh up to the third zone. The marsh height will increase, due to the import and the internal redistribution of sediments. The rear part (the fourth zone) will only experience minor siltation in creeks and depressions. This part will increasingly become lower compared to the proximal part and drainage could be hampered. The area will attain the characteristics of a backmarsh.

At this moment there is no certainty towards which scenerio the marsh will develop. Due to the siltation of the main ditch towards the fourth zone and the decrease in the tidal range in the rear part of the marsh, it is expected that the second scenario will be right. Critical for the tidal flow in the marsh is the passage at the bridge. If this is to be enlarged and deepened, tidal propagation will certainly increase. The first will become more likely.

LESSONS FOR FUTURE PROJECTS

Centuries of empoldering have formed the present geometry of the Scheldt estuary, with hardly any lateral flooding areas left. Together with deepening of the navigation channel over the past decades, this has resulted in a strong increase of tidal wave propagation and further loss of wetland habitats. Recently, researchers and policy makers both in Belgium and The Netherlands, have pointed out the important economical and ecological link between the maintenance of safe sea walls and increase of wetland area. Those areas have the potention to act as bufferzones, lowering the extreme high waters (flood parks). The use of wetlands as flood parks can be combined with the nature restoration and compensation program for the loss of habitats due to the deepening of navigation channel to the port of Antwerpen.

The accidental breaching and the formation of a tidal marsh at Sieperdaschor is a very welcome 1:1 scale "*experiment*" of tidal wetland restoration. It serves important information to researchers and policy makers on processes and time scales of marsh formation. But it can also serve as an important example for politicians, local authorities and last but not least the public (Smit & Pethick, 1996), who eventually will decide whether this kind of wetland restoration will be executed on larger scale.

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The morphodynamics of a sill in the Schelde Estuary (The Netherlands) and the influence of maintenance dredging activities

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ABSTRACT

Extensive dredging in the Schelde Estuary in the last 40 years has influenced the morphology in such a way that important ecological habitats have reduced in size. A new dredging program is about to be initiated and the authorities are in search of a way to optimize the dredging activities in order to reduce the negative effects of dredging. As the dredging activities mainly take place on the sills, the morphodynamic behaviour of the sills is studied. As a first step extensive measurements of the currents, the sediment transport and the morphological development were done in order to investigate the morphodynamic processes.

INTRODUCTION

The Schelde Estuary is located in the southern part of the North Sea (Figure 1.A) and is the fairway to the ports of Vlissingen and Terneuzen in the Netherlands and Antwerpen in Belgium (Figure 1B). The latter is one of the main ports in Europe. Antwerpen is located on the upper parts of the Schelde Estuary, 80 km upstream of the mouth. The estuary is macro-tidal with a tidal range of 3.8 m near the mouth up to 5.2 m near Antwerpen. The sediment is mainly sandy, has a median diameter of about 300 μm and rather low volumes of the fine fraction. The morphology of the Schelde Estuary is highly dynamical. The Schelde Estuary is considered as an ecological important brackish area with large amounts of shallow water, intertidal flats and salt marshes.

Since the beginning of this century the dredging activities, concentrated in the eastern part of the Schelde Estuary, guarantee a fairway with a sufficient depth to the port of Antwerpen. In the 1950's the volume of dredging in the estuary was about 5.10^6 m^3/yr. The dredging volume has increased to 8.10^6 m^3/yr due to a dredging program executed in the 1970's (Vroon et al., 1996). Most dredged material is dumped elsewhere in the Schelde Estuary. The continuous cycle of dredging and dumping of sediments has a large influence on the hydrodynamics